

Global to Regional Climate Simulation
A Workshop in the Bridging Disciplines, Bridging Scale Series

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Location: [Inn and Spa at Loretto](#), Santa Fe, New Mexico ([Google Map](#))

Dates: August 3-5, 2011

Melissa Bukovsky, National Center for Atmosphere Research, bukovsky@ucar.edu
Qingshan Chen, Florida State University, qchen3@fsu.edu
Noah Diffenbaugh, Stanford University, diffenbaugh@stanford.edu
James Done, National Center for Atmospheric Research, done@ucar.edu
Li Dong, Los Alamos National Laboratory, ldong@lanl.gov
Joe Galewsky, University of New Mexico, galewsky@unm.edu
Peter Gent, National Center for Atmospheric Research, gent@ucar.edu
Bereket Habtezion, Stanford University, bereket1@stanford.edu
Jim Hack, Oak Ridge National Laboratory, jhack@ornl.gov
Samson Hagos, Pacific Northwest National Laboratory, samson.hagos@pnnl.gov
David Ham, Imperial College, david.ham@imperial.ac.uk
Lucas Harris, NOAA Geophysical Fluid Dynamics Laboratory, lucas.harris@noaa.gov
Christiane Jablonowski, University of Michigan, cjablono@umich.edu
Xiaoyan Jiang, Los Alamos National Laboratory, xiaoyan@lanl.gov
Joe Klemp, National Center for Atmospheric Research, klemp@ucar.edu
Peter Korn, Max Planck Institute for Meteorology, peter.korn@zmaw.de
Peter Lauritzen, National Center for Atmospheric Research, pel@ucar.edu
Ruby Leung, Pacific Northwest National Laboratory, Ruby.Leung@pnl.gov
Mike Levy, Sandia National Laboratory, mnlevy@sandia.gov
Mat Maltrud, Los Alamos National Laboratory, maltrud@lanl.gov
Wieslaw Maslowski, Naval Postgraduate School, maslowsk@nps.edu
Linda Mearns, National Center for Atmospheric Research, lindam@ucar.edu
Mark Petersen, Los Alamos National Laboratory, mpetersen@lanl.gov
Sara Rauscher, Los Alamos National Laboratory, rauscher@lanl.gov
Todd Ringler, Los Alamos National Laboratory, ringler@lanl.gov
Anji Seth, University of Connecticut, anji.seth@uconn.edu
Bill Skamarock, National Center for Atmospheric Research, skamaroc@ucar.edu
Allison Steiner, University of Michigan, alsteine@umich.edu
Mark Taylor, Sandia National Laboratory, mataylo@sandia.gov
Bob Walko, University of Miami, rwalko@rsmas.miami.edu
Qiang Wang, Alfred Wegener Institute, Qiang.Wang@awi.de
Dylan Ward, University of New Mexico, djward@unm.edu
Tom Whittaker, University of New Mexico, twhittak@unm.edu
David Williamson, National Center for Atmospheric Research, wmson@ucar.edu
Nigel Wood, Met Office, nigel.wood@metoffice.gov.uk

Wednesday, August 3, 2011

7:30 - 8:30	Breakfast provided and Check In (Tesuque Room)
8:30 - 9:00	T. Ringler: Workshop Objectives
9:00 - 9:45	N. Diffenbaugh: Challenges and Prospects in Regional Climate Modelling
9:45 - 10:15	L. R. Leung: Development of Frameworks for Robust Regional Climate Modeling: Results from WRF Aqua-Planet Experiments
10:15 - 10:45	Break
10:45 - 11:15	W. Maslowski: Global and regional climate model requirements and limitations in the Arctic
11:15 - 11:45	J. Done: Dynamical and Statistical Modeling of Regional Climate Extremes
11:45 - 12:15	L. Mearns: Temperature Extremes in the NARCCAP Simulations: Evaluation and Uncertainty in Future Changes
12:15 - 1:45	Lunch provided (Acoma Room) and Posters (Tesuque Room)
1:45 - 2:30	M. Taylor: The Good, the Bad and the Ugly of Running the Community Atmosphere Model (CAM) at High Resolution
2:30 - 3:00	J. Hack: Ultra-High Resolution Global Coupled Climate Modeling
3:00 - 3:30	Break
3:30 - 4:00	M. Maltrud: Results from a Prototype Fully-Coupled Fine-Resolution CCSM Simulation
4:00 - 4:30	P. Gent: Is Eddy-Resolving Ocean Resolution Necessary to Simulate Regional Climate Change in the Southern Hemisphere?
4:30 - 5:00	S. Rauscher: Discussion and Wrap Up

Posters for Wednesday, August 3, 2011 (Please set up during breakfast):
Melissa Bukovsky, Bereket Habtezion, Samson Hagos, Peter Lauritzen, Anji Seth

Thursday, August 4, 2011

7:30 - 8:30	Breakfast provided (Tesuque Room)
8:30 - 9:15	B. Skamarock: Global Atmospheric Simulation using Variable Resolution Meshes
9:15 - 9:45	L. Harris: A two-way nested global-regional dynamical core on the cubed-sphere grid
9:45 - 10:15	B. Walko: Challenges of Modeling Convection on Grids with Spatially-Varying Resolution
10:15 - 10:45	Break
10:45 - 11:15	C. Jablonowski: High-order methods and nonhydrostatic designs on quasi-uniform and variable-resolution grids: Tackling the numerical challenges for future-generation GCMs
11:15 - 11:45	D. Williamson: Some aspects of time steps, time scales and scale awareness in the CAM parameterization suite
11:45 - 12:15	A. Steiner: Short-lived climate forcings and scale-dependent processes
12:15 - 1:45	Lunch provided (Acoma Room) and Posters (Tesuque Room)
1:45 - 2:30	N. Wood: A UK perspective on a twenty year journey towards seamless modelling across all space and time scales
2:30 - 3:00	P. Korn: The ICON Ocean Model - A Mimetic Discretization of the Ocean Primitive Equations
3:00 - 3:30	Break
3:30 - 4:00	D. Ham: How do you fit the climate on a graphics card? Engineering climate software for the hardware revolution.
4:00 - 4:30	Q. Wang: Ocean modeling with the Finite Element Sea-ice Ocean Model
4:30 - 5:30	T. Ringler: Discussion and Wrap Up

Posters for Thursday, August 4, 2011 (Please set up during breakfast):
Li Dong, Xiaoyan Jiang, Mike Levy, Mark Petersen

Friday, August 5, 2011

7:30 - 8:30	Breakfast provided (Tesuque Room)
8:30 - 9:15	Open, TBD
9:15 - 9:45	J. Galewsky: Tropical cyclones in a changing climate: Lessons from model simulations of the Last Glacial Maximum and Holocene.
9:45 - 10:15	S. Rauscher: Analysis of the MPAS hydrostatic dynamical core in aqua-planet mode
10:15 - 10:45	Break
10:45 - 12:15	Wrap Up
12:15 - 1:30	Lunch provided (Acoma Room)

Wednesday, August 3, 2011

Challenges and Prospects in Regional Climate Modelling, Noah Diffenbaugh

Development of Frameworks for Robust Regional Climate Modeling: Results from WRF Aqua-Planet Experiments, L. Ruby Leung and Samson Hagos

Predicting the regional hydrologic cycle at time scales from seasons to centuries is one of the most challenging goals of climate modeling. Because hydrologic cycle processes are inherently multi-scale, increasing model resolution to more explicitly represent finer scale processes may be a key to improving simulations of the hydrologic cycle. The robust regional climate modeling project is a collaborative effort among four DOE National Laboratories to use a hierarchical approach to test the veracity of global high resolution, global variable resolution, and nested regional climate model for regional climate modeling. The evaluation hierarchy includes four stages: 1) Idealized, no physics test cases, 2) Idealized, full physics test cases, 3) Real world, atmosphere-only and ocean-only simulations, and 4) Real world, coupled atmosphere-ocean simulations for both current and future climate. At each stage, simulations will be performed using global models at uniform coarse and high resolution, global variable resolution models with high resolution in the area of interest and low resolution elsewhere, and nested regional climate models with lateral boundary forcing provided by global coarse resolution models. To date, idealized full physics tests using Aqua-Planet Experiment have been performed by all modeling approaches. Results from the Weather Research and Forecasting (WRF) model will be presented to assess the effects of model resolution and model nesting on intra-seasonal variability and hydrological cycle of the tropics.

Global and regional climate model requirements and limitations in the Arctic, W. Maslowski, J. Kinney, A. Roberts, J. Cassano, W. Gutowski, D. Lettenmaier, A. Craig, M. Higgins, J. Jakacki, R. Osinski, C. Zhu

The majority of global climate models (GCMs) have significant limitations in their representation of past and present variability in the Arctic. In particular, GCMs that participated in the Intergovernmental Panel for Climate Change Fourth Assessment Report (IPCC-AR4) on average are too conservative in their representation of the observed summer sea ice cover trends. The inability of climate models to reproduce the recent warming and ice melt in the Arctic Ocean reduces their accuracy of future climate predictions. Some of these limitations include: northward oceanic heat fluxes, air-ice-sea interactions, distribution and variability of sea ice in the Arctic Ocean, and its export into the North Atlantic. The general tendency in those models is to transport warm Atlantic Water via the Barents Sea, with Fram Strait experiencing mostly outflow to the south. In reality, the West Spitsbergen Current flowing along the eastern part of Fram Strait delivers the majority of heat into the Arctic Ocean, while most of the heat entering

the Barents Sea is released to the atmosphere before entering the central Arctic. More importantly, the heat advected by Summer Pacific Water through Bering Strait is distributed by local currents and eddies over the Chukchi Shelf and into the Beaufort Sea and is readily available for melting sea ice in the western Arctic, where most of the ice retreat has taken place. We argue that high resolution is required to realistically model the flow of Pacific Water and the associated heat advection to address GCM limitations and their ability to realistically simulate sea ice variability in the western Arctic. This means that the magnitude of oceanic heat input to the Arctic Ocean and its impact on the sea ice might be significantly under-represented both in space and time in global GCMs, which may help explain their conservative predictions of warming and ice melt there. On the other hand, the majority of existing regional higher resolution Arctic models do not account for important sea-ice-atmosphere feedbacks. They either simulate the atmospheric state using simplified lower boundary conditions for sea ice and ocean or predict sea ice-ocean variability using prescribed atmospheric forcing. However, many of these processes and feedbacks impose critical controls on both regional Arctic and on global climate variability and their realistic representation requires dedicated high-resolution modeling studies and it is critical to improved climate predictions. The Regional Arctic Climate Model (RACM) is under development to address some of these limitations. It consists of atmosphere, land-hydrology, ocean and sea ice components. The model domain covers the pan-Arctic region and includes all sea-ice-covered regions in the Northern Hemisphere as well as all terrestrial drainage basins that drain to the Arctic Ocean. The overarching goal of this project is to advance understanding of past and present states of arctic climate and to improve seasonal to decadal predictions. This presentation will review details of model development and discuss selected results from stand-alone ice-ocean and fully coupled RACM simulations.

Dynamical and Statistical Modeling of Regional Climate Extremes, James Done

Current regional climate models have been used to provide information on climate extremes of societal relevance, yet these datasets are often limited in duration and detail and have largely unknown uncertainty. For the case of tropical cyclones, regional models may be run long enough to generate statistics of storm frequency and location but at the expense of capturing the full range of tropical cyclone intensity, sub-system scale structure and the upscale feedback on the general circulation. The opportunities and challenges in modeling regional climate extremes will be discussed with focus on tropical cyclones. The value of parallel dynamical and statistical model development will be explored, not only in characterizing the extreme events but also in assessing their societal impacts. Methods of combining dynamical and statistical approaches are largely unexplored and provide a fertile ground for interdisciplinary collaboration and progress.

Temperature Extremes in the NARCCAP Simulations: Evaluation and Uncertainty in Future Changes, Linda Mearns and Melissa Bukovsky

Extremes of maximum temperature and their potential change with human induced climatic change are important from the point of view of human health, livestock well being, crop productivity, and potential forest fire hazard. In this presentation we evaluate the reproduction of temperature extremes (daily and monthly) in the suite of North American Regional Climate Change Assessment Program (NARCCAP) regional climate model (RCM) simulations and examine the simulations of future climate regarding how the frequency of such events may change. We particularly examine the uncertainty in the changes in frequency of extremes by analyzing the multi-RCM ensemble of future simulations. Both the frequency of single day events and runs of extreme temperature days will be examined in the NCEP-driven simulations as well as the GCM-driven simulations. In evaluating the models' ability to reproduce such extremes we examine what aspects of bias in the mean and higher order moments of the temperature time series are most responsible for bias in the frequency of extreme events.

The Good, the Bad and the Ugly of Running the Community Atmosphere Model (CAM) at High Resolution: Mark Taylor, Kate Evans, Peter Lauritzen, Art Mirin, Saroj Mishra, Pat Worley

The Community Earth System Model (CESM) is now capable of performing climate-length integrations at high resolution on DOE's latest petascale computers. The recently released version 1.0.3 includes an ultra-high resolution, with all components running at close to 10km horizontal resolution, runs at 2.6 simulated years per day. Much of this performance is due to the new spectral element atmospheric dynamical core in the CESM's atmosphere component CAM. Here I will describe some results from CAM with this dynamical core, from resolutions ranging from 1 degree (110km) down to 1/8 degree (13km). There are many aspects of the simulated climate which do improve with increasing resolution, related to resolving additional scales such as storms, topographic effects and variability. Many aspects of the simulated climate are tied to the physical parametrizations and show no improvement under increasing resolution, as expected. However, some aspects such as those related to cloud microphysics degrade significantly under mesh refinement.

Ultra-High Resolution Global Coupled Climate Modeling. J. Hack et al.

Results from a Prototype Fully-Coupled Fine-Resolution CCSM Simulation, Mathew Maltrud, Julie McClean, David Bader, and a host of others

Results are presented from a fully coupled multi-decadal CCSM simulation whose grid resolutions were 0.1° for the ocean and ice, and 0.25° for the atmospheric and land components. The model realistically developed intense category 4 tropical cyclones and the upper ocean response. Also, the model realistically reproduced the structure and pathways of explicitly resolved Agulhas ocean eddies, the main constituent of the upper limb of the Atlantic meridional overturning circulation. However, the Polar atmospheric vortices were excessively contracted and intensified, producing cold sea surface temperature biases and excessive ice cover in the Northern Hemisphere. In addition, we discuss some of the difficulties and other issues involved with performing simulations at this scale. Undeterred, we will outline our path forward in this arena.

Is Eddy-Resolving Ocean Resolution Necessary to Simulate Regional Climate Change in the Southern Hemisphere? Peter Gent, NCAR

A PetaApps project coupled $1/2$ degree atmosphere/land components to $1/10$ degree ocean/sea ice components of the CCSM4, and a control run of 155 years was completed. A 1% increasing CO₂ run was branched at year 77, run until year 147 when CO₂ is doubled, and then for another 15 years with constant CO₂. Similar control and 1% CO₂ runs were made in a configuration with the same atmosphere/land components coupled to the standard 1 degree CCSM4 ocean/sea ice components. The question is whether the parameterized eddy effects in the 1 degree ocean component result in a similar climate change as when the eddies are resolved? This question is not easily answered because the size of climate change expected depends on the climate state of a control run, and the two control runs have significantly different climates. However, the Southern Hemisphere differences are much smaller than in the north because the Antarctic sea ice distributions are much more similar than in the Arctic. The analysis will concentrate on the region of the Antarctic Circumpolar Current, which is known to be eddy-driven and is where the eddy parameterization is most likely to be found wanting. Preliminary results will be presented.

Thursday, August 4, 2011

Global Atmospheric Simulation using Variable Resolution Meshes, Bill Skamarock, NCAR/MMM

Numerical simulation of the global atmospheric circulation began in the 1950s and by the 1970s primitive equation models were producing daily NWP forecasts. In the 1970s limited-area models began to be used to downscale these forecasts using 1-way nesting techniques. Two-way moving nest models were first developed in this same time period to provide high resolution simulations of hurricanes. One and two-way nested modeling systems remain in use today for operational and research NWP

applications and for regional climate applications. An alternative refinement approach is to use conforming meshes where resolution varies smoothly. The conforming meshes alleviate a number of problematic issues inherent in the traditional nested mesh approaches where abrupt non-conforming mesh transitions can lead to serious grid imprinting and unphysical solutions. In this talk we will review the issues associated with traditional nesting and consider the advantages of the conforming-mesh models for locally-refined global atmospheric simulation, and we will illustrate these points with examples from existing models (e.g. WRF) and from the Model for Prediction Across Scales (MPAS) which we are currently developing that uses conforming variable-resolution Voronoi meshes. We will also briefly consider the implications of the new global meshes for regional climate applications with respects to experimental design and needed model development and testing.

**A two-way nested global-regional dynamical core on the cubed-sphere grid.
Lucas Harris, GFDL**

A global-to-regional nested-grid model is constructed using the Finite-Volume dynamical atmosphere core on the cubed sphere. The use of a global grid avoids the need for externally-imposed lateral boundary conditions, and a consistent solution is produced by using the same governing equations and discretization on the global and regional domains. The nested-grid boundary conditions are simple interpolation into the nested-grid halo, and two-way updates use a simple averaging method that conserves scalar quantities and vorticity. In particular, mass conservation in a two-way nested simulation is simply done by not updating the mass field. Despite the simplicity of the nesting methodology, nested-grid simulations of a series of common idealized test cases show favorable results, as the large-scale solutions are not corrupted by the nested grid. There is also evidence that the nested grid is able to improve the coarse-grid solution, even beyond the boundaries of the nest.

**Challenges of Modeling Convection on Grids with Spatially-Varying Resolution,
Bob Walko, University of Miami**

This talk considers the problem of how to represent convection in a model with highly variable horizontal resolution. Ideally, convection should be resolved where the grid is fine enough, while it must be parameterized elsewhere. However, it will be demonstrated using idealized simulations that transitioning smoothly between these two regimes is highly challenging. The simulations further show that even when resolved, convection can be sensitive to grid scale and to its gradient. Some conceptual approaches to overcoming these problems will be discussed, along with early progress toward a particular method.

High-order methods and nonhydrostatic designs on quasi-uniform and variable-resolution grids: Tackling the numerical challenges for future-generation GCMs. Christiane Jablonowski and Paul A. Ullrich

Numerical predictions of high-impact local weather events and the vastly growing demand for regional-local climate predictions are grand challenge problems and one of the main drivers for novel atmospheric models that are ready for high-performance computing architectures. Future-generation atmospheric General Circulation Models (GCMs) and their dynamical cores will likely rely on both high-order accuracy and variable-resolution techniques in order to seamlessly capture the multi-scale flow regimes. The talk surveys the design of conservative and highly accurate numerical methods for an Adaptive-Mesh-Refinement (AMR) dynamical core of a GCM. In particular, the talk discusses a fourth-order finite-volume scheme for a nonhydrostatic dynamical core on a cubed-sphere grid that makes use of an implicit-explicit Runge-Kutta-Rosenbrock time integrator and Riemann solvers. The talk overviews the algorithmic steps, presents results from idealized dynamical core test cases and outlines the inclusion of AMR via the grid library Chombo into the model design.

Short-lived climate forcings and scale-dependent processes. Allison Steiner, University of Michigan

Climate model simulations provide a method to assess the anthropogenic influence of short-lived chemical species such as tropospheric ozone and atmospheric aerosols. However, many of the processes that affect these short-lived compounds and the resulting forcing are scale-dependent. Here, we use a regional climate model with a simplified aerosol scheme to investigate two questions of scale: (1) the impact of the emission inventory resolution on surface aerosol forcing and (2) the impact of climate model resolution on surface aerosol forcing. Anthropogenic aerosol concentrations of sulfate, black carbon (BC) and organic carbon (OC) are simulated using a high-resolution (25 km) regional climate model for two emission inventories, representing two scales of lower boundary conditions: (1) The 1°x1°EDGAR inventory and (2) the 4 km US Environmental Protection Agency (EPA) National Emissions Inventory (NEI) 1999. A third coarse resolution (60 km) simulation using the EPA inventory tests the effect of climate model resolution. Evaluation of modeled concentrations versus observations indicate that the emission inventory selection has relatively small impacts on the model simulation of aerosols, with some minor differences in the summertime due to the simulation of sulfate chemical conversion in the model. The greatest differences in surface forcing are attributed to the climate model resolution and wet removal of aerosols. These results indicate that modeled aerosol forcings from a regional climate model are more sensitive to climate model resolution than anthropogenic emissions inventory, which has implications for climate model simulations at all resolutions.

Some aspects of time steps, time scales and scale awareness in the CAM parameterization suite. David L. Williamson

We study the problem of truncation-scale storms characterized by extreme vertical motion and heavy precipitation that form in high resolution versions of CAM4. The problem arises when some individual parameterizations do not return the state to an atmospheric-like state because they are restrained by the time-scales assumed in their formulation. Other unconstrained parameterizations then work in unintended ways. We examine the behavior of the moist parameterization components for one typical, strong cell. At T340 spectral truncation with a 5 minute time step, the deep and shallow convection parameterizations do not remove instabilities and supersaturation because they have time scales of 1 hour and 30 minutes, respectively. Then, the prognostic cloud water scheme, which is not constrained by a time scale, removes all supersaturation. That local release of latent heat drives very strong vertical motion and horizontal convergence which transports even more water vapor into the column, exacerbating the problem. Two simple model problems are introduced that illustrate the ramifications of the time-scale and time step mismatch. When either the time scales are shortened or the time step is lengthened the convection parameterizations are more active and the strong storms do not form. The problem is also evident in 0.25 degree CAM5 simulations with 15 minute time steps. The problem does not occur at lower resolutions leading to greater and artificial scale dependence of the current CAM parameterization suite. We conclude that parameterizations should be formulated without an explicit time scale in such a way that they complete their processes in a single application.

A UK perspective on a twenty year journey towards seamless modelling across all space and time scales. Nigel Wood, UK MetOffice

Twenty years ago saw the first operational run of the global version of what was to become the UK Met Office's Unified Model. Two years later this same model was used for climate simulations and finally the mesoscale model was retired and replaced by a limited-area version of the Unified Model. The original concept of a unified modelling system was that all model configurations would share the same dynamical core and the same modelling framework. This philosophy was primarily driven by a need for greater efficiency. But over the last decade the scientific advantages of this approach have become increasingly clear and this has driven a desire for a much more comprehensive unification - the seamless goal. However, differences in the specific parameters used in those parametrizations still remain and in particular our decadal prediction system is based on the original modelling system. Removing these final seams presents many challenges in various areas. This talk will review the history of the Unified Model, discuss the advantages and disadvantages of such an approach (both in terms of the science and the organisation itself) and, particularly from a dynamical core perspective, consider the challenges of moving to even greater unification.

The ICON Ocean Model - A Mimetic Discretization of the Ocean Primitive Equations. Peter Korn, Max Planck Institute for Meteorology

The Max Planck Institute for Meteorology and the German Weather Service have been collaborating closely through the ICON project to develop new coupled atmosphere-ocean general circulation models for climate research and numerical weather forecasting. As a member of the ICON modeling system a new ocean model has been developed. This talk provides an overview of the ICON project with an emphasis on the dynamical core of the ocean component. The three-dimensional, hydrostatic, Navier-Stokes equations on the rotating sphere and with a free surface are solved on a triangular z-coordinate grid. In order to obtain conservation of discrete dynamical invariants a new spatial discretization has been developed that is based on the method of mimetic finite differences. We describe the properties of the discretized equation and present a sequence of simulations. The numerical experiments range from unforced two-dimensional simulations to three-dimensional stratified flow simulations with wind forcing an realistic topography.

How do you fit the climate on a graphics card? Engineering climate software for the hardware revolution. David Ham, Imperial College

The push towards much higher resolution climate models coincides with a radical change in computer hardware which has been underway for the last five years and is expected to continue for the foreseeable future. The new hardware platforms include GPUs, multicore CPUs and emerging architectures such as the Intel Knights series. This hardware is characterised by a massive degree of fine-grain parallelism at a level which has not been seen since the demise of the vector computer nearly 20 years ago.

Climate simulation software is also characterised by a massive level of inherent parallelism which places the field in a better position to exploit the current explosion in computational power than many other applications. However, the different platforms emerging are very heterogeneous and require invasive code changes in order to exploit the capacity of the hardware. It is not even the case that a single programming language is applicable to all of the emerging platforms. Furthermore, new architectures are emerging every year. Climate models require massive effort over many years to develop, tune and validate. Their code bases are expected to remain in use for many years and it takes several years to bring a new model into use. For instance, the UK Met Office is currently investigating the development of a new dynamical core for the Unified Model which might go into operational use in 9 or 10 years time. How then are we to develop the next generation of climate models if the optimal implementation changes so fast?

In this presentation, I will present an overview of the work of the Multilayer Abstractions for Partial Differential Equations (MAPDES) project. The core concept of this software engineering framework is to separate the specification of the numerical discretisation

from the parallel implementation. This is achieved by specifying the numerical schemes as local operations on local data and indicating the relationship of those local operations to the underlying mesh topology. The parallel implementation of this operation, including domain decomposition, colouring, threading and data format changes is then conducted by a specialised compiler taking into account the characteristics of the underlying hardware. I will present the initial development of the MAPDES infrastructure and show some initial results which demonstrate both the computational power of these new platforms and the degree of low-level code change which is required to achieve them.

Ocean modeling with the Finite Element Sea-ice Ocean Model, Qiang Wang

FESOM is an unstructured mesh ocean model based on the finite element method and hydrostatic primitive equations. Both the ocean and ice modules are discretized on the same triangular 2D mesh, allowing direct exchange of fluxes and fields. Narrow straits and complex coastlines can be faithfully resolved by varying the horizontal resolution. Regional processes and responses can be resolved with regionally refined resolution on a global mesh without traditional nesting. Examples of FESOM applications will be presented. Discussions will be focused on some challenging aspects of development and application of unstructured mesh ocean models.

Friday, August 5, 2011

Analysis of the MPAS hydrostatic dynamical core in aqua-planet mode. Sara A. Rauscher, Todd Ringler, Bill Skamarock, Art Mirin

We present results from the MPAS (Model for Prediction Across Scales) hydrostatic atmospheric dynamical core implemented within the DOE-NCAR Community Atmospheric Model (CAM). MPAS is an unstructured-grid approach to climate system modeling that supports both quasi-uniform and variable resolution meshing of the sphere using quadrilaterals, triangles, or Voronoi tessellations. Because grids are conforming (no hanging nodes), MPAS is amenable to local mesh refinement. Therefore it can be run as a global high-resolution model, variable resolution model, or regional climate model. The MPAS atmospheric dynamical core uses a finite-volume approach using C-grid (normal velocities at cell edges). In order to evaluate this new regional modeling capability, several idealized test cases have been performed, including aqua-planet simulations. Results from a suite of aqua-planet experiments with increasing horizontal resolution are in line with other CAM results: in general, tropical precipitation increases with resolution, while cloud fraction decreases. As expected, the physical parameterizations are sensitive to mesh resolution. An equatorward shift in mass is also present in the higher resolution simulations. An analysis of tropical waves reveals the presence of both Kelvin waves and strong westward propagating Rossby waves. Analysis of the kinetic energy spectrum indicates that the effective resolution of the model is about eight times the horizontal grid spacing. In summary, we have designed a

numerical method where the multi-resolution mesh does not adversely impact the dynamics (i.e. we maintain all conservation properties, do not require ad hoc stabilization methods and do not degrade accuracy when using a multi-resolution mesh). In the short term we anticipate that using multi-resolution meshes with standard coarse and fine mesh resolutions (e.g. 120 km / 25 km) along with the commensurate parameter settings in each region will allow us to obtain scientifically useful results regarding regional climate processes.

Tropical cyclones in a changing climate: Lessons from model simulations of the Last Glacial Maximum and Holocene. J. Galewsky, R. Korty and S. Camargo

Climate change and tropical cyclone (TC) climatology is a problem that inherently spans a broad range of scales and has been the subject of a rapidly growing body of work. Both the observational record and general circulation models' (GCM) prediction of the next century's climate have been studied to learn how TC frequency, tracks, and intensity may change with the evolving large-scale environment. We are presently adopting many of the techniques successfully used to study TC climatology in a future climate for analysis of two periods in the geologic past: the Last Glacial Maximum (LGM) and mid-Holocene 6000 years ago (6ka). We are analyzing how large-scale factors known to influence TC genesis and maintenance differ in GCM simulations of the paleoclimates and are comparing them to the present day simulations of the same models. By focusing on climate states that are very different from either the present day or from projected future anthropogenic warming scenarios, this study will provide new insights into the links between TCs and the large-scale environmental factors that control them, and will provide an improved foundation for studies of how tropical cyclones have impacted the geological record. These large-scale environmental factors, which include maximum potential intensity, the thermal and humidity profiles of the tropical atmosphere, low-level vorticity and wind shear, evolve in a complex way: while sea surface temperatures (SST) at the LGM were uniformly colder, our preliminary analysis shows that the thermodynamic environment actually was more favorable for TC genesis in some tropical regions while in others it was more hostile. Additionally, we are adopting a dynamical downscaling approach to simulate TC genesis in a regional model. We plan to apply techniques similar to those adopted for anthropogenic climate change simulations for the LGM and 6ka by running regional versions of WRF with a PMIP multimodel ensemble average defining the climate change deviation. There are several important details to consider when applying downscaling techniques to a paleoclimate environment, however, and part of this project will be devoted to identifying the configuration best suited to paleoclimate applications.

Posters: Wednesday, August 3, 2011

Temperature Trends in the NARCCAP Regional Model Simulations, Melissa Bukovsky

In this study we will analyze simulations from the North American Regional Climate Change Assessment Program (NARCCAP) in terms of their ability to reproduce the 2-m temperature trends of the late 20th century over North America. Trends will be compared to the driving reanalysis (the NCEP-DOE global reanalysis II: R2) as well as multiple observation-based datasets for 1980-2004. Likewise, available global climate model (GCM) driven NARCCAP simulations will be examined relative to their drivers and observations from roughly 1970-1999 and compared to their reanalysis driven counterparts. We will also explain some large discrepancies in the regional climate model (RCMs) trends. Current work indicates that some biases in trend are due to model drift. Differences in trends will be discussed in the context of current regional responses to greenhouse warming, implications for bias correction, and uncertainty in future climate projections.

NARCCAP is producing high-resolution climate simulations over North America for the generation of regional climate change scenarios for impacts and uncertainty research. Simulations are produced by six different RCMs given conditions from 4 different global climate models for present and future conditions using the 20c3m and A2 SRES scenarios and the R2 reanalysis.

High Resolution WRF Modeling of the Western USA: Comparisons with Observations and large scale Gridded Data, Bereket Lebassi-Habtezion and Noah Diffenbaugh

Mesoscale effects are not accounted in global models due to the coarse resolution of the latter. These mesoscale effects could be very important in modifying the microclimate of local regions. For example sea breezes, urbanization, irrigation, mountain/valley circulations etc. modify and feedback local climate. In this study we use the mesoscale Weather Research and Forecast (WRF) Model to evaluate its performance against station observations, gridded observations, and large-scale reanalysis data over the entire Western USA. Simulations are carried out for summer (JJA) 2010 at three resolutions of 4, 25 and 50kms, covering the entire Western USA. July surface temperature, relative humidity, wind speed and direction observations are compared with model results of the three resolutions. Results showed that 4k WRF performed best while 50km WRF performed the least in capturing the daytime 10m wind speeds and directions. However, larger daytime surface temperature and humidity biases were shown while nighttime performance was generally good for all resolutions. Summer time 2D comparisons of 4km WRF and 4km PRISM data showed consistent results of warm bias in California Central valley and southern part of the domain. These biases are small in June and got larger in July and August. This could be due to underestimation of moisture from irrigation in Central Valley and monsoon rainfall in the

southern domain. Finally, comparisons between 4k WRF forced by NCEP reanalysis and NARR was undertaken. Results showed that WRF-NCEP had warm bias in the coastal California and cold bias in the northern part of the domain while most part of the domain did not show significant changes.

Energetics of the sensitivity of a regional model to spatial resolution, Samson Hagos and L. Ruby Leung

Multi-scale analysis of the energy budget of a set of WRF simulations at resolutions ranging from 100km to 4km, with and without cumulus parameterizations, is used to assess the roots of the sensitivity of model hydrology and circulation to spatial resolution. As model resolution increases, additional processes involving eddy flux convergence of moisture and to a lesser extent heat come to play. In our simulations, the heating associated with these eddy fluxes is generally underestimated by the cumulus parameterization in the corresponding low-resolution simulations. This leads to the sensitivity of the model resolution. Furthermore the contribution of feedback through the resolved circulation to this sensitivity is quantified.

Evaluating advection/transport schemes using interrelated tracers, scatter plots and numerical mixing diagnostics. Peter H. Lauritzen (NCAR) and John Thuburn (University of Exeter, UK)

Atmospheric tracers are often observed to be functionally related, and these relations can be physically or chemically significant. It is therefore highly desirable that the transport schemes used in chemistry and chemistry-climate models should not disrupt such functional relations in unphysical ways through numerical mixing or, indeed, unmixing. Here, diagnostics are proposed that quantify numerical mixing by a transport scheme for a single tracer, two tracers that are nonlinearly related, and three (or more) tracers that add up to a constant. For the two-tracer test the question of how physically reasonable the numerical mixing is can be addressed by using scatter/correlation plots. Truncation errors will, in general, result in scatter points deviating from the preexisting functional curve and thereby introduce numerical mixing between the tracers. The proposed diagnostics quantify the mixing in terms of the normalized distances between the preexisting functional curve and scatter points, and divide it into three categories: real mixing and two types of spurious numerical unmixing. For the three-tracer test we quantify, in terms of standard error norms, how nearly a transport scheme can preserve the sum by transporting the individual tracers.

The mixing diagnostics do not require the knowledge of the analytical solution to the transport problem for the individual tracers. However, using an idealized flow field and spatial distributions facilitates the use of the mixing diagnostics in transport scheme development. Hence we propose to exercise the new mixing diagnostics using an idealized but highly deformational analytical flow field. Example results using the CSLAM (Conservative Semi-Lagrangian Multi-tracer) scheme are presented.

Response of Regional Monsoons to Global Warming in CMIP3 Projections **A. Seth, S. A. Rauscher, M. Rojas, A. Giannini and S. J. Camargo**

Twenty-first century climate model projections show an amplification of the annual cycle in tropical precipitation with increased strength in both wet and dry seasons, but uncertainty is large and few studies have examined transition seasons. We analyze coupled climate model projections of global land monsoons and find a redistribution of precipitation from spring to summer in northern (North America, West Africa and Southeast Asia) and southern (South America, Southern Africa) regions. Two mechanisms are examined through the annual cycle, one remote (based on tropospheric stability) and one local (based on low level and surface moisture). Increases in tropospheric stability persist from winter into spring and are reinforced by a reduction in surface moisture conditions, suggesting that in spring both remote and local mechanisms act to inhibit convection. Based on these results two discussion questions follow. First, does the current emphasis on annual (or warm season) rainfall in monsoon regions obscure coherent changes within the annual cycle? Second, what effects might higher spatial resolution have on these results?

Posters: Thursday, August 4, 2011

How Do Vegetation Growth and Water Table Dynamics Affect Regional Simulation of Warm Season Precipitation? Xiaoyan Jiang, Guo-Yue Niu and Zong-Liang Yang

It is one of the great challenges to predict precipitation on timescales from days to years at regional scales. The hope to improve intraseasonal to seasonal precipitation forecasts relies on simulating the atmospheric response to slowly varying states of the land surface and the ocean. In this study, we hypothesize that including vegetation growth and groundwater dynamics in a regional climate model can improve intraseasonal to seasonal predictions of precipitation and have a strong effect on the coupling between the land and the atmosphere over the Central U.S. We used the Weather Research and Forecasting model, which is a non-hydrostatic, fully compressible model with complete physical parameterizations. Our results show that the model with the considerations of vegetation and groundwater dynamics successfully reproduces summer precipitation over the Central U.S. In this region, the default model produces less precipitation compared to observations. When vegetation growth is included, more precipitation is seen, as perhaps induced by vegetation-atmosphere feedback. When a groundwater module is added to the model in addition to vegetation growth, the performance is further enhanced, which could be due to the possible interactions between vegetation and groundwater. These results also suggest that vegetation growth and groundwater dynamics play an important role in enhancing the persistence of intra-seasonal precipitation in regional climate models.

A First Look at the MPAS-A Dynamical Core in Real-World Simulation. Li Dong, Todd Ringler, Sara Rauscher and Art Mirin

We integrated the MPAS dynamical core into the CESM and carried out a 6-year simulation at 1-degree resolution using the F-configuration (active atmosphere and land, prescribed sea-ice and data ocean). By post-processing with AMWG diagnostics package, we compare simulations by MPAS to the default finite volume dynamical core in CESM 1.0. The preliminary results indicate a close resemblance in simulations by these two dynamical cores. Based on these preliminary results, we tentatively judge the MPAS-A model to be a promising dynamical core.

A Variable Resolution Spectral Element Dynamical Core in the Community Atmospheric Model, M. Levy, J. Overfelt and M. Taylor

NCAR's High Order Method Modeling Environment (HOMME) provides a spectral element dycore in the Community Atmosphere Model (CAM). HOMME has been updated to allow static refinement via conforming quadrilateral meshes on the cubed sphere, and this poster compares uniform 2 degree and 1 degree meshes with refined meshes that transitions between the two resolutions for a baroclinic test case and the aqua-planet experiment.

The baroclinic instability test spins up a wave in the northern hemisphere, and we find that refining strictly in the northern hemisphere is sufficient to resolve the wave as well as the uniform high resolution case. The aqua-planet test resolves a region centered on the equator and show the statistics from the refined region match those of the high resolution run while the statistics from the unrefined region match those of the low resolution run.

A Variable Resolution Global Ocean Model. M. Petersen, et al.

The Model for Prediction Across Scales (MPAS) is a software framework for the rapid development of climate model components on unstructured grids. The grids may be quasi-uniform or variable density, on a sphere or rectangular domain, and may use quadrilateral cells, triangle cells, or Voronoi tessellations. MPAS variable-density grids are particularly well suited to regional climate simulations. MPAS is developed cooperatively by NCAR MMM and the LANL COSIM team.

The MPAS-Ocean component now includes most of the features of a full ocean-climate model. High resolution global simulation with full bathymetry have been run for hundreds of simulated years and produce realistic currents. Current efforts focus on barotropic/baroclinic timestepping and improving performance.